An Examination of PFAS for North Carolina Policymakers and Researchers

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Executive Summary

This Master's Project examines the current literature reported on the occurrence of per- and polyfluoroalkyl substances (PFAS) in the environment, and explores data concerning their occurrence, distribution, and relative prevalence across North Carolina. PFAS are of interest to better understand in North Carolina for several reasons. First, several types of PFAS chemicals have been linked to detrimental health effects in children and adults. Second, various PFAS chemicals, including some of those with negative health impacts, have been detected in North Carolina waterways that supply drinking water across the state. Finally, while it is not currently understood what are the critical levels of risk that many of these PFAS compounds present to individuals who use the water on a regular basis, it is important to understand the populations that are potentially exposed to PFAS and how best to remediate such exposure and mitigate the health risks associated with PFAS occurrence in drinking water.

The background and literature review sections of this Master Project describes a variety of aspects for the currently available knowledge for PFAS, and identifies under-researched topics as well as unexplored gaps in knowledge on FPAS occurrence in the environment. This section starts with defining PFAS compounds and introducing their unique properties, types, potential sources, and routes of exposure. The section also covers mechanisms and negative effects of exposure in humans in general, in vulnerable populations such as children and in organisms in the ecosystem. It further discusses acceptable levels of exposure and compares the effectiveness of PFAS removal options, followed by a summary of the occurrence, transport, and fate of PFAS in the environment. The last two parts of the literature review section provide the historical background of a major PFAS manufacturer, describe the scope and consequences of its contamination and point out the

possibility of overlooking many other factories that may be involved in PFAS production and discharges.

The policy regulation section lays out significant actions taken by the U.S. EPA and North Carolina Health and Quality departments to address PFAS issues, difficulties of moving toward enforceable and more stringent regulatory policies, and the status of plans for future policy and regulations efforts.

The analysis section draws heavily from data synthesis of two North Carolina Department of Environmental Quality (DEQ) datasets: 2018 Emerging Compounds Monitoring Reports of various watersheds and public water supply (PWS) reservoirs and the 2019 Publicly Owned Treatment Works (POTW) three-month sampling study. It starts with presenting evidence not only of legacy PFAS compounds (PFOA and PFOS) but emphasizes the diversity – and dominance – of other analytes and abundance of short-chained PFAS in NC waterways. Further analysis highlights the importance of using total PFAS level for a better understanding of the true extent of contamination and suggests the need to re-examine sampling sites that had high reporting limits to detect PFAS occurrence issues that likely have been overlooked. While ongoing sampling efforts from the PFAS Testing Network indicates that hydrological, seasonal, and directional factors all affect how the contamination is distributed, a variety of confusing patterns still await for well-grounded and conclusive scientific explanations. The last portion of this section discusses populations that have a higher exposure risk and emphasizes the critical need for extensive at-tap testing to perform a household-level risk assessment.

The discussion and recommendations section acknowledges the limitations of available remediation options, reviews regulation considerations, and considers the cost implications of both. First, it reaffirms the relevancy of Granular Activated Carbon (GAC) and Reverse Osmosis

(RO) methods in the context of PFAS present in North Carolina. Given the abundance of short-chain analytes, RO is likely the appropriate choice but there are health risks associated with de-mineralization that needs to be addressed prior to implementation. Next, regulatory options are presented. In particular, the best practice to regulate by class (total PFAS) might not be feasible to enact and therefore this section discusses the notable implications for the other options that should be considered prior to passing enforceable limits. This concludes with a reflection on the costs associated with various interventions demonstrates a range of budget expectations using examples from other municipalities upgrading their treatment systems.

Lastly, a four-page mitigation memorandum is included in this document as a possible stand-alone product that can communicate the summary results of this project in a concise manner for non-technical audiences. It briefly touches upon each section that has been thoroughly reviewed in this document and emphasizes the analytical results from the two DEQ datasets and integrates these with policy, remediation, and risk assessments. Based on user needs, this memorandum is organized so that it can appropriately and easily be split into two products: a two-page memo on mitigation options and another two-page memo covering summary knowledge and identified gaps in the scientific literature pertaining to toxicology, occurrence, and distribution.

Introduction

Per- and polyfluoroalkyl substances (PFAS) are commonly produced for manufacturing processes of textiles and water-resistant coatings and have been used in household goods such as non-stick pots and pans, clothing and furniture fabrics, and heat resistant plastic coatings of electronics for over 60 years (Barzen-Hanson et al., 2017). PFAS compounds have been highly considered in the past for their stability and hydrophobicity, and for this reason have been used in many water-resistant products. PFAS compounds derive their stability from strong carbon-fluorine

bonds, which are especially hard to break by natural processes such as biodegradation, and are commonly made through electrochemical fluorination and telomerization (Olsen et al., 2017). Generally, more carbon-fluorine bonds result in higher resistance to degradation, and therefore, PFAS chemicals with longer-chains can become more abundant in water resources with higher potential for health effects such as neurotoxicity (Gaballah et al., 2020).

In North Carolina, PFAS compounds have been used in wastewater treatment facilities, plastic and textile manufacturing sites, and fire training areas where foam extinguishers are used (Olsen et al., 2017). Of particular concern are industries in North Carolina that specialize in fluorochemical manufacturing and the processes by which they dispose of their waste, both currently and in the past. Several studies have documented a few manufacturers in North Carolina with wastewater containing fluoroethers like GenX ($C_6H_4F_{11}NO_3$) discharged to waterways, such as the Cape Fear River as early as 1980 (Nadine Kotlarz et al., 2020). Additionally, some less well-known PFAS chemicals have been generated during the production of target fluorochemicals such as PFOA and PFOS and were seen as by-products of production, but have raised concern in recent years due to their similarities to these target PFAS chemicals and their potential risk to human health (Gaballah et al., 2020). Because these compounds have been produced extensively across a range of manufacturing and industry needs, PFAS chemicals can be found nearly everywhere in the environment, including in dust, soil, surface water, and groundwater, and some have shown the ability to bioaccumulate in humans and other organisms (Herkert et al., 2020a). High levels of PFAS compounds have been identified in several rivers in North Carolina, including the aforementioned Cape Fear River, which has been the subject of several studies for the impact on drinking water from several communities in NC (Foguth et al., 2020; Nadine Kotlarz et al., 2020; Sun et al., 2016a).

Exposure to various PFAS compounds at differing levels and life stages has been linked to degenerative health impacts, including developmental and reproductive effects, lower child birth weight, thyroid hormone disruption, various types of cancer, liver impairment, endocrine disruption, and immune system degradation (Li et al., 2020; Pelch et al., 2019). Children and infants are of particular concern for this class of chemicals, as some research has suggested exposure to PFAS compounds in childhood can lead to greater detrimental health consequences later in life (Anderko & Pennea, 2020). In North Carolina, several studies have examined PFAS in individuals, examining levels in blood samples compared to levels in home tap water (N Kotlarz et al., 2019; Nadine Kotlarz et al., 2020). While these studies have examined the amount of PFAS bioaccumulating in individuals in North Carolina, limited research has yet been conducted on the direct outcomes of increased exposure in humans. Currently, reverse osmosis (RO) filtration is widely accepted as one of the most efficient methods of removing PFAS from drinking water source, but limitations exist as such systems often include lofty upfront costs of installation and force low flow rates, which can limit the usefulness of such RO systems (Horst et al., 2018).

While PFAS chemicals are considered a class of emerging contaminants, some steps have been taken at the national level to limit exposure to certain chemicals within this class. Because of the ability of PFAS compounds to persist in nature, and due to the association between long-chain PFAS compounds and negative human health consequences, some of the PFAS compounds have garnered the attention of U.S. regulatory agencies. For example, the U.S. Environmental Protection Agency (EPA) has recently codified a health advisory level (HAL) of 70 parts per trillion (ppt) for the combined quantity of perfluorooctanesulfonic acid (PFOS) and perfluorooctanoic acid (PFOA) in drinking water (Li et al., 2020). Although more attention has presently been given to long-chain compounds, some studies have found detrimental effects associated also with short-chain PFAS

compounds, where prenatal exposure was found to be of considerable concern (Nian et al., 2020). While more research is needed to accurately assess the dangers of short-chain PFAS, both individually and in combination with other types of hazardous chemicals, concern has been raised over the ramifications of attempting to designate each individual chemical as a hazardous substance, and how listing PFAS compounds as such would cause many new Superfund sites to be listed across the U.S. due to their PFAS contamination (Simon et al., 2019).

As PFAS contamination continues to pose a threat to ecological and human health, we aimed to conduct meaningful analysis through this Master's Project thesis on PFAS contamination occurrence in NC in order to present a full picture of the urgent issue and identify knowledge gaps. We have compiled these knowledge gaps at the conclusion of our report, along with several other tools for policymakers. We visualized data collected by the North Carolina Department of Environmental Quality into several informational maps and graphics to better identify PFAS contamination across the state. We have also summarized our recommendations for North Carolina policymakers based on our review of the issue in a policy memo included at the end of this report.

Background and Literature Review

What are PFAS Chemicals?

PFAS describes per- and poly-fluoroalkyl substances, which are a class of man-made chemicals and include PFOA ($C_8HF_{15}O_2$), PFOS ($C_8HF_{17}O_3S$), GenX ($C_6H_4F_{11}NO_3$), and a number of other related compounds (U.S. Environmental Protection Agency, n.d.-a) As this name suggests, the chemicals in this class are distinguished by their structure, which broadly consists of a fluorinated carbon chain with differing functional groups. PFAS compounds are known for their stability, and derive this stability from many strong carbon-fluorine bonds. These carbon-fluorine bonds are especially hard to break by natural processes such as biodegradation, and are commonly

made through electrochemical fluorination and telomerization (Olsen et al., 2017). Generally, more carbon-fluorine bonds result in higher resistance to degradation, and therefore, PFAS chemicals with longer-chains can become more abundant in water resources with higher potential for health effects such as neurotoxicity (Gaballah et al., 2020). Currently, while over 5,000 different types of PFAS have been identified, PFOS and PFOA have been most widely produced and studied (Davis, 2019; Smith & Davis, 2019; U.S. FDA, n.d.). Generally, PFAS compounds are used in industry to produce fluoropolymer coatings and manufactured products that involved heat, oil, stain, grease, and water resistant (Centers for Disease Control and Prevention, n.d.). Because of this, PFAS chemicals have been used historically in the production of furniture, food packaging, adhesives, clothing, heat-resistant non-stick cooking surfaces, electrical wire insulation, and many other products (Centers for Disease Control and Prevention, n.d.). PFAS chemicals have also been used in fire-fighting foams, and some studies have found increased levels of PFAS chemicals in bodies of water near fire-fighting stations and training facilities (Buck et al., 2011; Wang et al., 2015). General trends in several physical-chemical properties have been noted in most PFAS compounds, including high water solubility (Le et al., 2021; Scher et al., 2018; Yamashita et al., 2008), low volatility (Horst et al., 2018; Kelly et al., 2009; Pancras et al., 2016), and as previously noted, resistance to biodegradation (Fujii et al., 2007; Pickard et al., 2020). These characteristics can vary by the structure of the chemical and can be related to chain length and type of functional group. One such trend has been noted when examining the half-lives of PFAS chemicals with varying chain lengths, and researchers found that as PFAS chain length increased, half-lives in those exposed also increased (Xu et al., 2020). PFAS compounds as a class are also notable for their ability to bioaccumulate in a variety of organisms, as they often bind well with proteins (Haukås et al., 2007; Kannan et al., 2001; Martin et al., 2003; van de Vijver et al., 2003)

Some variability has been noted between the half-lives and bioaccumulation potentials of different types of PFAS. In one study, researchers found that levels of GenX in exposed subjects were very low, suggesting a short half-life, but also found elevated levels of other, newly identified types of PFAS that have been less well studied (Scruggs, 2019). For these reasons, the physical and chemical structure of PFAS compounds indicate they have differential potential to accumulate in water bodies and in individual organisms, and that certain compounds may have the ability to accumulate even after long periods of time after initial use. Some research has also noted the ability of certain PFAS to attach to dust particles and transport via the air, and to migrate from food packaging and water into food products, which may account for up to 50% of all human PFAS exposure (Brown et al., 2020; Pelch et al., 2019; Sunderland et al., 2019). Because of this, the primary method of human exposure remains elusive for researchers, and therefore remains difficult to manage through targeted remediation efforts (Sunderland et al., 2019).

Human Health Impacts of Exposure

PFAS chemicals have been linked to a variety of negative health impacts in humans. Currently, it is thought that these negative effects are due to the ability of many PFAS compounds to mimic internal ligands and disrupt signaling pathways in the body, including thyroid hormone pathways, leptin signaling pathways, estrogen signaling pathways, and other metabolic pathways (Jiang et al., 2015; Kjeldsen & Bonefeld-Jørgensen, 2013). Several studies have linked PFAS exposure to both testicular and kidney cancer, although these results have not been seen across all studies, and tend to suggest that only excessive exposure to PFAS chemicals can illicit this response in adults (Barry et al., 2013; Eriksen et al., 2009; Vieira et al., 2013). Other diseases have also been linked to adult exposure to PFAS, including thyroid disease, high cholesterol, ulcerative colitis, and hypertension during pregnancy, as well as decreased vaccine response, decreased

fertility, and low infant birthweight (ATSDR, n.d.; Darrow et al., 2013; Lopez-Espinosa et al., 2012; Steenland et al., 2013; Sunderland et al., 2019). Studies in model organisms have suggested the potential for other, less well-studied health effects in humans. While genotoxicity has not been found to be significant in any studies involving mice, some research has pointed to further disruption of the lymphatic system as well as decreases in immune system efficacy and inhibition of protein transfer at the blood-brain barrier in affected mice (Cannon et al., 2020; Crebelli et al., 2019; Frawley et al., 2018). Accurate risk characterization of various PFAS chemicals for adult humans remains elusive, however, as most data currently available regarding the health impacts of PFAS have been conducted on populations accidentally exposed to high levels of various compounds or model organism studies, which can also be challenging to translate and scale down to human risk (Barry et al., 2013; Chou & Lin, 2019; Scher et al., 2018; Sun et al., 2016b; Vieira et al., 2013; Xu et al., 2020). Similarly, while several studies have looked into the occurrence of differing PFAS compounds in North Carolina water systems, connection between the occurrence of these chemicals and the adverse health effects seen in controlled environments has yet to be investigated (Bangma et al., 2020; Cahoon, 2020; Nadine Kotlarz et al., 2020; Saleeby et al., 2021; Sun et al., 2016c; Sunderland et al., 2019).

Impacts of Exposure on Children

It has been well documented that PFAS exposure poses a larger risk to children than to adults, due to the fact that children consume more water per their bodyweight, and therefore larger PFAS impact from drinking water (Pelch et al., 2019; Reade et al., 2019). Also, some research has shown that children may be more vulnerable to PFAS due to their developing immune systems and body growth (Apelberg et al., 2007; Johnson et al., 2014; Rappazzo et al., 2017). Studies have found evidence that PFAS exposure in children is associated with abnormal amounts of blood

lipids, later onset of menstruation, limited immunity, higher occurrence of asthma, and limited kidney function (Rappazzo et al., 2017). Furthermore, studies in mice have found that in-vivo PFOS exposure to natal subjects resulted in delays in mammary gland development, even at the lowest doses tested, suggesting PFAS exposure to infants in the womb may be of the highest concern (Macon et al., 2011; Tucker et al., 2015; White et al., 2011). Further studies in PFAS-exposed human infants have found associations between heightened PFAS serum levels and reduced immune response before and after vaccination, increased risk of celiac disease (CD), increased risk of type 1 diabetes, and increased morbidity (McGlinchey et al., 2020; Sinisalu et al., 2020; Timmermann et al., 2020). Because of these heightened risk factors for children and infants, the EPA has based their health advisory levels on the impacts on the most vulnerable in the population, and has set the health advisory level for PFOS and PFOA at 70 ppt (U.S. Environmental Protection Agency, n.d.-b). So far, limited research has linked other, less well-known types of PFAS to definitive health responses in humans, but studies suggest some may have a similar capacity to cause damage as their better known counterparts. Laboratory studies in which animals were exposed to different levels of GenX, for example, have shown adverse effects to the liver and blood, along with liver, pancreatic, testicular and uterine cancers, but there is no information about whether these or other health effects would be seen in humans (Giesy & Kannan, 2001; Ji et al., 2008).

Ecological Impacts of Exposure

Because of their ubiquitous nature in the environment, studies have found accumulation of PFAS in other organisms, particularly those that develop or thrive in water. PFAS chemicals have been detected in organisms ranging from freshwater macro-invertebrates, such as *Daphnia magna* and *Moina macrocopa,* to polar bears in the arctic, showing that PFAS exposure has spread across

all facets of the world (Giesy & Kannan, 2001; Ji et al., 2008). The global spread of PFAS exposure and accumulation has been linked both to specific events where large amounts of PFAS were dumped into the environment, as well as continued use practices from a variety of sources, resulting in higher levels of PFAS in the organisms studied (Ding & Peijnenburg, 2013; Hamid et al., 2018; Nakayama et al., 2019; Sinclair et al., 2020). There is limited information, however, about whether these concentrations of PFAS, which are relatively low in most natural ecosystems, are having a significant impact on the organisms' accumulating of the chemicals (W. Liu et al., 2019; Sasaki et al., 2003). Nevertheless, accumulation in certain species is still of higher concern to humans, as consumption of these species may contribute significantly to additional PFAS intake and consequent accumulation in humans. Several studies have linked PFAS contamination with increased accumulation in fish species (Giesy & Kannan, 2001; Ji et al., 2008; Nakayama et al., 2019; Sinclair et al., 2020). This is especially concerning for populations who may consume more fish than average and predatory organisms who may get most of their nutrition from consuming fish. For example, a 2019 study in South Carolina has found that 83% of studied fish species contained more PFOS than the advisory levels set to protect mammals, suggesting excessive fish consumption may contribute to unsafe levels of PFOS accumulation (Fair et al., 2019).

Acceptable Levels of Exposure

In the U.S., the EPA has established health advisory levels for a variety of potentially harmful chemicals. By basing estimates on prospective risk to the most vulnerable populations, the EPA has established a health advisory level of 70 ppt for combined PFOA and PFOS (U.S. Environmental Protection Agency, n.d.-b). Despite this, some research has shown that these levels may be too lenient for infants and children, as consumption of 70 ppt would increase PFOS and PFOA above the current national background levels, and may cause immunosuppression in

children (Cordner et al., 2019; Grandjean & Clapp, 2015). Seven individual states have set their own advisory levels for PFOS, PFOA, and PFAS mixtures which range from 13 to 1000 ppt, and include advisories for both individual and total concentrations of PFAS in the environment. Further research has identified 1 ng/L as the threshold level from which would cause no increase in population-based serum levels across U.S. national averages (Cordner et al., 2019; Grandjean & Clapp, 2015). These estimates fall in line with the current understanding of PFOS and PFOA accumulative exposure, and may be accurate for other types of PFAS as well. North Carolina currently uses the standard of 70 ppt set by the EPA for PFOS and PFOA, and has a statewide goal of less than 140 ppt for GenX in all state drinking water (North Carolina Department of Health and Human Services, 2020). Because PFOS and PFOA have the ability to bioaccumulate, it is currently assumed that an individual's blood serum PFOA level may be as high as 100 times the amount of PFOA in their drinking water (Reade et al., 2019a). Currently, the EPA has not set advisory levels for any other PFAS chemical beyond PFOS and PFOA. While limited research has found conclusive evidence of harm to human health from other individual PFAS compounds, an argument has been raised that PFAS chemicals should not be regulated individually, but instead as a class of chemicals (Blum, 2016; Cordner et al., 2016; Cousins et al., 2020; Kwiatkowski et al., 2020). Some researchers studying PFAS have contended that because common traits exist across most chemicals categorized as PFAS compounds, including high potential for accumulation, persistence, and known and unknown health damages, the entire class should be regulated together out of precaution for future, currently unknown damages (Cordner et al., 2016; Cousins et al., 2020; Kwiatkowski et al., 2020). A similar approach has been taken by several countries in the European Union, including Norway, Denmark, Germany, the Netherlands, and

Sweden, where plans have been introduced to phase out nearly all PFAS compounds by 2030 (Council of the European Union, 2019).

Potential for PFAS Degradation and Removal

Because of their physical and chemical properties, PFAS compounds are characteristically hard to break down in nature (Alzate-Sánchez et al., 2019; Cui et al., 2020; Singh et al., 2019). Some evidence has pointed to the ability of certain of PFAS chemicals to go through physiochemical changes in soil and water that result in shorter alkyl chains, however, this is widely recognized to not be the norm across the class (Cui et al., 2020). Several alternative, non-naturally occurring methods have been identified for their ability to break down or trap PFAS compounds, including advanced reduction processes (ARPs), plasma-based water treatment, and use of β-cyclodextrin polymers (Reade et al., 2019). While these technologies show promising results, there are still significant hurdles to full adoption in widespread PFAS removal practices. Particularly examining ARPs, several unknowns within the field offer challenges for researchers when attempting to solidify ARPs as a viable PFAS treatment option, including high production and energy costs associated with the technology being in early development, limited knowledge of the toxicity of PFAS transformation products after treatment, and limited efficiency due to the technology's aptitude to react with other constituents in the water (Reade et al., 2019). Currently, the most widely accepted and cost-efficient methods of removing PFAS from potable water involve using activated carbon (GAC), ion exchange technology, and reverse osmosis (RO) filtration to remove contaminants (Reade et al., 2019). GAC has been used for nearly 15 years as a treatment to remove various types of PFAS, and according to the EPA, is effective as an adsorbent due to its porous nature and high surface area for contaminants to adsorb (Reade et al., 2019; U.S. Environmental Protection Agency, 2018).

PFAS Cycle

The complexity of the PFAS cycle indicates the many pathways that PFAS can be released into the environment. The transport and fate of PFAS from point and nonpoint sources is highly relevant for the extent of potential human and wildlife exposure. The following section is primarily about identifying and explaining the components and interactions within the PFAS cycle.

Factories involved in PFAS manufacturing and usage may contribute significant loads of PFAS to adjacent aquatic systems like streams, rivers and lakes through direct discharge of untreated wastewater. It is also likely that wastewater from factories will be diverted to designated wastewater treatment plants before entering the waterways. However, wastewater treatment plants may serve as another major source of contamination as many facilities lack the filtration capacity to effectively remove all of the PFAS (Barnes, 2020a). As a result, the discharge of post-treatment wastewater will continue to foul nearby rivers. Some research indicates that the effluent may contain a higher level of stable form of PFAS subclasses like PFCAs and PFSAs than the influent due to the biodegradation processes of labile precursors compounds (Loganathan et al., 2007; Post et al., 2012). Generated by wastewater treatment plants, some of the biosolids will act as fertilizers for agricultural lands. In the US, half of the biosolids end up being applied to sites where crops and animals are raised, leading to the potential of the uptake and bioconcentration of PFAS by plants and animals (EnviroScience, 2019). Food products from those lands, if consumed by humans on a regular basis, will raise concerns about the associated health effects of PFAS exposure. PFAS from the land-application sites may also move through soil and ultimately infiltrate into groundwater. Admittedly, PFAS-impacted surface water and groundwater will have a huge impact on the quality of drinking water supplies serving certain communities.

Another significant source of PFAS is the extensive use of PFAS-based firefighting foams in military fire training areas and civilian airports (U.S. Department of Defense, 2019). The application of PFAS in aqueous film-forming foam (AFFF) gives the mixture its low surface-tension properties and facilitates the spread across fuels, which is powerful for extinguishing flammable liquid fires (The PFAS Project Lab, 2017). Besides the possibility of entering surface water, PFAS-containing foams may also make their way into groundwater through recharge (Liu et al., 2016).

Landfills are effective carriers of PFAS compounds (Bloomberg Law, 2020). Landfill leachate, which is a highly polluting fluid, is essentially a collection of rainwater, dumped liquid and garbage decomposition (Bloomberg Law, 2020). If chemicals arriving at landfills involve PFAS compounds, leachate functions as an ideal sink for trapping those contaminants. It is important to know that leachate can be transported to wastewater treatment plants. The problem is whether the treatment facilities are advanced enough to target PFAS removal. If not, the outgoing water is anticipated to discharge PFAS-contaminated effluent to rivers.

It is recognized that air emissions from responsible factories is a way in which PFAS can be introduced to the environment, which is supported by evidence showing deposition and the detection of PFAS in rainwater (U.S. Environmental Protection Agency, 2019). The presence of some PFAS chemicals have also been detected in indoor environments, which provides another route of exposure (Michigan.gov). The indoor occurrence is attributed to the release from PFAS-containing consumer goods such as stain-resistant carpets, cookware, waterproof clothing to air and dust (Zheng et al., 2020).

What Types of Industry Can Generate PFAS Contaminants?

Contamination sources are significant contributors to many occurrence and distribution issues. The purpose of identifying who is illegally producing and discharging PFAS-contaminated water into aquatic systems is meant to solve the root of the problem. Losing the supply of PFOA from 3M company, DuPont began its own manufacturing in North Carolina (Riley, 2020). As PFOA became phased out, DuPont began GenX manufacturing without informing the North Carolina Department of Environment Quality of the unfavorable effects similar to PFOA (Zimmerman, 2017). The secret was kept until June 2017, when the discharge and detection of GenX in Cape Fear River was exposed by Wilmington Star News, sparking a great deal of concern and controversy (Barnes, 2020b). As a spin-off from Dupont, Chemours officially owned the Fayetteville Works manufacturing site along the Cape Fear River in 2015 (Barnes, 2020a, 2020b). It is believed that DuPont did conduct investigations to understand the characteristics and potential risks of PFOA as early as the 1960s (Union of Concerned Scientists, 2019). DuPont knew from laboratory testing about the toxic effects of GenX but still secretly released the chemical that tainted the Cape Fear River (Clabby, 2017). Nafion manufacturing area and polyvinyl fluoride manufacturing area of the Fayetteville Works Facility provide sources of PFAS contamination (Gisler and Zhuang, 2018). PFAS contamination is not limited by physical boundary and makes its way to Wilmington and Brunswick County (Barnes, 2020b). Further evidence proved that PFAS observed in water samples acquired from NC coastal cities' drinking water intake had been tied to the Chemours plant located 89 miles upstream from the intake (Walton, 2020). The portion of the Cape Fear that the facility is discharging into is designated as a Class C water area. By definition, Class C waters are considered to be freshwaters protected for secondary recreation, fishing, aquatic animals and wildlife (Gisler and Zhuang, 2018). In addition to the contamination occurring at the

discharge point and adjacent area, there is a critical area located a few miles downstream. The critical area is essentially an area where risks associated with contamination are greater than the same contamination happening elsewhere in the watershed (Gisler and Zhuang, 2018). Despite the extensive negative impact that Dupont has had on the Cape Fear River Basin, it is not the single industry that should be paid attention to and regulated. As requested by DWR, Lear Corporation and Arclin USA should conduct further PFAS testing for their effluent discharge due to previous effluent testing results (Managing Emerging Compounds in Water, n.d.). However, Chemours, Lear Corporation and Arclin USA are probably the tip of the iceberg. The high risks of PFAS contamination in NC is mostly likely to be attributed to the presence of a variety of industrial and military sites within the state (Duke Today Staff, n.d.).

What Factories Are Overlooked?

In addition to the well-known key players that are responsible for major PFAS contamination in North Carolina, there are other companies/sources that are potential targets for either first-time or continual investigation. Despite the great attention paid to Chemours and DuPont due to their long-term dumping behavior, many other corporations in the Cape Fear River basin are suspected of using PFAS and therefore need to be scrutinized (Woolverton, 2020). For some testing groups that only focus on where the contamination occurs and what the concentrations are, source identification would not fall within their main objectives. Some researchers linked PFAS detection in sewer plants with the use of firefighting foam in military and airport training sites (Woolverton, 2020). In Greensboro, for example, the firefighting foam previously used at Piedmont Triad International Airport was deemed to be a dominant source of PFAS compounds in water (Woolverton, 2020). In Pittsboro, it is inferred that the river was presumably the source of contamination as wells were not found to be contaminated (Ross, 2020).

In regions of Cumberland and Bladen counties where high levels of PFAS occurred, it was challenging to trace PFAS back to its source because some places were upstream from the Chemours plant (Ross, 2020). PFAS may also come from landfills, metal plating and finishing, textiles, resins, rubber, adhesives, pesticides, cement additives (U.S. Environmental Protection Agency, 2018). Mining, photographic, electronics and semiconductor industries can all be contributors of PFAS contamination through multiple pathways (U.S. Environmental Protection Agency, 2018).

Current Policy Regulation

While there is no federal Maximum Contaminant Level (MCL) for PFAS, as a class or for individual compounds, the EPA established a 70 ppt (0.07 µg/L) health advisory for PFOS and PFOA individually, where the co-occurrence sum is the same level (U.S. Environmental Protection Agency, 2018). Based on toxicity assessments, this non-enforceable and non-regulatory advisory is intended to guide state agencies with technical information, health effects, and treatment technologies. Although the EPA initiated a toxicity assessment for GenX in 2018, they have yet to set a toxicity value, leaving a gap in enforceable regulation for GenX and other forms of PFAS that are not PFOS or PFOA (U.S. Environmental Protection Agency, n.d.-b, n.d.-a, 2018).

States have filled this gap of an enforceable regulation with their own state standards [Figures 1 and 2] (Reade et al., 2019). At least thirteen have approved or are in the process of approving an MCL for PFOA, PFOS, and other PFAS (Barnes, 2020b). As seen by Figure 1, these values are lower than the EPA's 70 ppt advisory due to other calculations and interpretations of toxicity. Michigan, for example, acknowledged that their MCL does not prevent the pollution from occurring or require installing remediation technology (those are better suited for discharge permits and other regulatory mechanisms) but it "will force the public utilities to install PFAS

filtration systems if they fail to meet the standards." All utilities in Michigan are required to annually test for PFAS, and are required to test quarterly if known contamination exceeds the threshold (Woolverton, 2020). Michigan has also established a multi-agency task force surrounding the issue of PFAS contamination and began testing public water supplies for PFAS in 2017 (Barnes, 2020b).

Figure 1. Selected Thresholds for Drinking Water and/or Groundwater - PFOA

Author	Threshold type	Threshold (ppt)	Critical Dose includes UFs (mg/kg/day)	Total UFs	Study Endpoint 2	Drinking water exposure assumptions	Notes
				PFOA			
USEPA	health advisory	70	2×10^{-5}	300	Developmental effects on bone growth and male puberty (Lau, 2006)	0.054 L/kg/day, 90th percentile for lactating women, RSC = 20%	combined with PFOS
Minnesota	guidance value	35	2×10^{-5}	300	Developmental effects on bone growth and male puberty, increased liver weights (Lau, 2006)	modeled for breast- or formula-fed infants, including fetal exposure, RSC = 50%	adopted guidance value - health risk limit - for groundwater
Vermont	health advisory	20	2×10^{-5}	n/a	based on EPA	0.175 L/kg/day for a infants less than 1 year of age, RSC = 20%	combined with PFOS, PFNA, PFHxS, PFHpA (also a ground water enforcement standard); to be adopted as a combined MCL
New Jersey	MCL	14	2×10^{-6}	300	Increased liver weights (Loveless, 2006) + UF for mammary gland effects	0.029 L/kg/day, default adult assumptions, RSC = 20%	proposed; groundwater criteria also proposed at 10 ppt
California	notification level	14	n/a	n/a	Developmental, immunotoxicity, liver toxicity, and cancer	n/a	interim notification levels based on NJ & ATSDR values
ATSDR	environmental media evaluation guide	21	3×10^{-6}	300	Developmental: altered activity, skeletal alterations (Onishchenko, 2011; Koskela, 2016)	0.143 L/kg/day for a infant, RSC = 100%	minimal details provided on calculation of drinking water concentrations from MRL
ATSDR - more protective	estimated MCL	3*	3×10^{-6}	300	Developmental: altered activity, skeletal alterations (Onishchenko, 2011; Koskela, 2016)	**0.175 L/kg/day for a infants less than 1 year of age, RSC = 20%**	*threshold for water based on ATSDR's minimal risk level (for total exposure)
NJ - more protective	estimated MCL	0.1	1×10^{-7}	30	**altered mammary gland development**	**0.175 L/kg/day for a infants less than 1 year of age, RSC = 20%**	using RfD calculated by New Jersey
Protective choices combined	**MCLG (goal)**	0.01	1×10^{-8}	300**	**altered mammary gland development**	**0.175 L/kg/day for a infants less than 1 year of age, RSC = 20%**	****an additional UF of 10, to protect fetuses, infants, children added**
**An additional uncertainty factor of 10 to protect fetuses, infants and children is recommended by the National Academy of Sciences (NAS 1993) for pesticides and as required in the Food Quality Protection Act. 21 U.S.C. §346a(b)(2)(C)(ii)(II).							

Figure 2. Selected Thresholds for Drinking Water and/or Groundwater - PFOS

Author	Threshold type	Threshold (ppt)	Critical Dose includes UFs (mg/kg/day)	Total UFs	Study Endpoint 2	Drinking water exposure assumptions	Notes
USEPA	health advisory	70	2×10^{-5}	30	Developmental: decreased pup weight (Leubker, 2005)	0.054 L/kg/day, 90th percentile for lactating women, RSC = 20%	combined with PFOA
Minnesota	guidance value	27	5×10^{-6}	100	Developmental: decreased pup weight (Leubker, 2005)	modeled for breast- or formula-fed infants, including fetal exposure, RSC = 50%	health-based value, provides technical guidance for groundwater
Vermont	health advisory	20	2×10^{-5}	n/a	based on EPA	0.175 L/kg/day for a infants less than 1 year of age, RSC = 20%	combined with PFOS, PFNA, PFHxS, PFHpA (also a ground water enforcement standard); to be adopted as a combined MCL
New Jersey	MCL	13	2×10^{-6}	30	Immunotoxicity: decreased plaque forming response (Dong, 2009)	0.029 L/kg/day, default adult assumptions, RSC = 20%	proposed; groundwater criteria also proposed at 10 ppt
California	notification level	13	n/a	n/a	Developmental, immunotoxicity, liver toxicity, and cancer	n/a	interim notification levels based on NJ & ATSDR values
ATSDR	environmental media evaluation guide	14	2×10^{-6}	300	Developmental: delayed eye opening, decreased pup weight (Leubker, 2005) + UF for immunotoxicity	0.143 L/kg/day for a infant, RSC = 100%	minimal details provided on calculation of drinking water concentrations from MRL
ATSDR - more protective	estimated MCL	2*	2×10^{-6}	30	Developmental: delayed eye opening, decreased pup weight (Leubker, 2005) + UF for immunotoxicity	**0.175 L/kg/day for a infants less than 1 year of age, RSC = 20%**	*threshold for water based on ATSDR's minimal risk level (for total exposure)
NJ - more protective	estimated MCL	2	2×10^{-6}	30	Immunotoxicity (Dong, 2009)	**0.175 L/kg/day for a infants less than 1 year of age, RSC = 20%**	
ATSDR - more protective	estimated MCL	0.02	2×10^{-8}***	30	**Immunotoxicity (Peden-Adams, 2008)**	**0.175 L/kg/day for a infants less than 1 year of age, RSC = 20%**	***critical dose estimated by ATSDR's MRL method
Protective choices combined	**MCLG (goal)**	0.002	2×10^{-9}	300**	**Immunotoxicity**	**0.175 L/kg/day for a infants less than 1 year of age, RSC = 20%**	****an additional UF of 10, to protect fetuses, infants, children added**
**An additional uncertainty factor of 10 to protect fetuses, infants and children is recommended by the National Academy of Sciences (NAS 1993) for pesticides and as required in the Food Quality Protection Act. 21 U.S.C. §346a(b)(2)(C)(ii)(II).							

Comparatively, North Carolina has yet to establish an MCL for PFOS, PFOA, or other PFAS that is different from the federal standard of 70 ppt. North Carolina uses the EPA's advisory as primary references for both surface and groundwater recommended standards, but DEQ officials acknowledge that an EPA Integrated Risk Information System assessment (which does not yet exist for PFOA or PFOS) would be first preference for guiding quality standards (Hegstad, 2019). North Carolina's Department of Health and Human Services (DHHS) set a provisional health goal (non-regulatory, non-enforceable) of 140 ppt for GenX. Rather than distinguishing 'safe' from 'dangerous' levels, 140 ppt represents "the concentration of GenX at which no adverse non-cancer health effects would be anticipated in the most sensitive population over an entire lifetime of exposure. The "vulnerable population" in question are "bottle-fed infants, the population that drinks the largest volume of water per body weight" (North Carolina Department of Health and Human Services, 2020). More recently, a collaborative effort known as the PFAS Testing Network has been established and funded through the North Carolina General Assembly, and is comprised of scholars from Duke, UNC- Charlotte, UNC-Chapel Hill, UNC-Wilmington, NC State, ECU, and NC A&T who specialize in PFAS testing and research (N.C. PFAS Testing Network, 2021).

EPA Involvement

The EPA has established a PFAS Action Plan, which is a non-enforceable document suggesting short-term and long-term strategies to address PFAS contamination. This plan encompasses the establishment of Superfund sites and MCL's, and also includes toxicology assessment conclusions and suggestions on how to work with states, tribes, and local government entities when examining PFAS policy (U.S. Environmental Protection Agency, 2019). In this plan, the EPA committed to making a "regulatory determination" under the Safe Drinking Water Act (SDWA) by the end of 2019, which would formally decide if the EPA will pursue a national

primary drinking water regulation (NPDWR) for a specific contaminant (Longsworth, 2020). Although the agency did not meet that deadline, on January 19, 2021 the EPA announced it will begin the process to develop a NPDWR for PFOS and PFOA and "intends to fast track evaluation of additional PFAS for future drinking water regulatory determinations if necessary information and data become available" (U.S. Environmental Protection Agency, 2021).

In North Carolina, the EPA has targeted the Chemours' Fayetteville Works plant for its contribution to various PFAS compounds in the Cape Fear River. Previously, the EPA had ordered Chemours' predecessor, DuPont, to eliminate 99% of its PFAS discharges in 2009, but the order failed to reach the field staff conducting inspections to ensure compliance (Woolverton, 2020). Andrew Wheeler, an EPA administrator under Trump, suggested that Chemours should switch its use away from GenX to a safer chemical, without naming an alternative. He stated that "some of the newer versions, we believe – have been approved by the EPA – to be safer than what they replace," referencing that new kinds of PFAS can only be manufactured with EPA permission to ensure public and environmental safety (Woolverton, 2020). While switching away from the use of GenX may offer some benefit in the short term regarding regulatory approval, it is important to recognize that this solution offered by Mr. Wheeler may not be the most useful option in the long-term, as it is currently unknown what health effects are caused by the replacements for GenX. Historically, GenX itself was created as a less dangerous alternative for PFOS and PFOA, and given the similarities among the chemical class, it may be true that the alternatives to GenX may follow a similar regulatory track once more information is gathered about their potential health impacts.

North Carolina Involvement

In response to an investigation and public pressure, Chemours stopped discharging GenX in June 2017, and that September, DEQ ordered Chemours to stop discharging wastewater into the Cape Fear River for "failure to adequately disclose the release of GenX into the river" (N.C. DEQ, 2017). Less than two years later, Chemours entered into a Consent Order with the DEQ in February 2019 (Consent Order, 2019). Due to high levels of PFAS in rain samples 20 miles away from the plant, DEQ required Chemours to "spend $100 million on a thermal oxidizer that the DEQ says has lived up to its expectations of removing 99.9% of airborne PFAS from the plant" (Barnes, 2020a; Scruggs, 2019).

Chemours was also required to provide bottled water or filtration systems to households on private wells if a single PFAS concentration measured above 10 ppt (Woolverton, 2020). Additionally, the Constant Order mandated that Chemours needed to have a treatment system removing over 99% of PFAS from the stream operable by September 30, 2019. Lastly, an addendum stipulated that Chemours needed to build a 2.4 km underground barrier to prevent contaminated groundwater from seeping into the river and capture stormwater to treat at the plant (Hogue, 2020).

Subsequently, DEQ ordered 25 municipalities near the Cape Fear River to test for PFAS at their sewer plants for three months, starting in July 2019 (N.C. DEQ, 2019). DEQ issued a Notice of Violation to Chemours on January 26, 2021 due to "exceeding an effluent limit, failure to meet flow requirements, improper operation and maintenance, and failure to mitigate during storm events" (N.C. DEQ, 2021). The failure, in part, was because Chemours failed to fully change the activated carbon in its filters and keep sediment out of its wastewater treatment system (Sorg, 2021). While DEQ continues monitoring outfall levels, there has been a "political paralysis" to

regulate PFAS in North Carolina after GenX (Ross, 2020). North Carolina's General Assembly has blocked any further attempts to control PFAS beyond the GenX/Chemours action, including rejecting regulatory efforts to reduce firefighter foam, where a statewide inventory of its use was the only legislative proposal that passed (Ross, 2020). Key legislators insist that PFAS contamination is a local issue in the Lower Cape Fear River watershed and used this justification to refuse to support DEQ's requests for additional resources and enforcement. Furthermore, industry lobbyists who did not wish for greater PFAS regulation influenced what legislation was passed by the North Carolina General Assembly, and further limited DEQ's testing abilities by the type of equipment available for use. This has limited the ability of DEQ to detect PFAS compounds at a lower resolution, and would allow for a better understanding of the PFAS compounds in water that are below current detection limits. Instead, the General Assembly appropriated $5 million to the PFAST Network to conduct a broader, statewide analysis of PFAS in North Carolina (Ross, 2020). Governor Cooper has extended funding of the network through October 15, 2020, but the COVID-19 pandemic has suspended the bulk of all sampling work and may have impacts on the results of sampling in the future (NC Policy Collaboratory, 2020).

Some assembly representatives support environmental reform and welcome broadened statewide MCL's for certain PFAS, but have voiced concerns over how such policies would actually affect PFAS regulation. Rep. Pricey Harrison, D-Greensboro, has stated his concern that targeted environmental reforms for specific chemicals would create a "whack-a-mole" game chasing industry's next PFAS compound (Woolverton, 2020). Researchers Harrison, DeWitt, and Birnbaum take this idea a step further and support regulating PFAS as a single class (Woolverton, 2020). Rep. Ashton Clemmons (D-Greensboro) filed a bill similar to those in 20 other states establishing both an MCL for total PFAS and regulations for two other probable carcinogens, 1,4

dioxane and hexavalent chromium, but within the week "it was referred to the House rules committee, where legislation typically goes to die" (Barnes, 2020b). Similarly, in April 2019, Kirk deViere (D-Cumberland) co-sponsored Senate Bill 518 to repeal the Hardison Amendment which prohibits DEQ from establishing environmental standards more stringent than the EPA – it died in committee along with five others on environmental regulations (Barnes, 2020b). Organizations that are heavily involved include NC Coastal Federation, NC Policy Collaboration, Haw River Assembly, and Southern Environmental Law Center, who is currently leading the class-action lawsuit against Chemours and involved in 20 other PFAS lawsuits in the country (Barnes, 2020b).

Analysis

Compounds

According to EPA's data associated with the Unregulated Contaminant Monitoring Rule (UCMR3), of those samples taken in North Carolina, the most common PFAS detected in drinking water was PFOA followed by PFOS contamination (Reade et al., 2019). Similarly, as GenX comes under the spotlight in recent years, both academic and public attention have been shifted to the detection and study of GenX. The claim of GenX dominance in well water was rebutted by research findings showing the detection of PFMOAA in Wilmington at concentrations 100 times higher than GenX (Woolverton, 2020). It is worth noting that drinking water downstream of Chemours and well water contained a worrisome level of Nafion by-product 2, another member of the PFAS family (Woolverton, 2020). Both examples can be used to illuminate the necessity of reconsidering how dominant PFAS compounds in the aquatic systems should be defined.

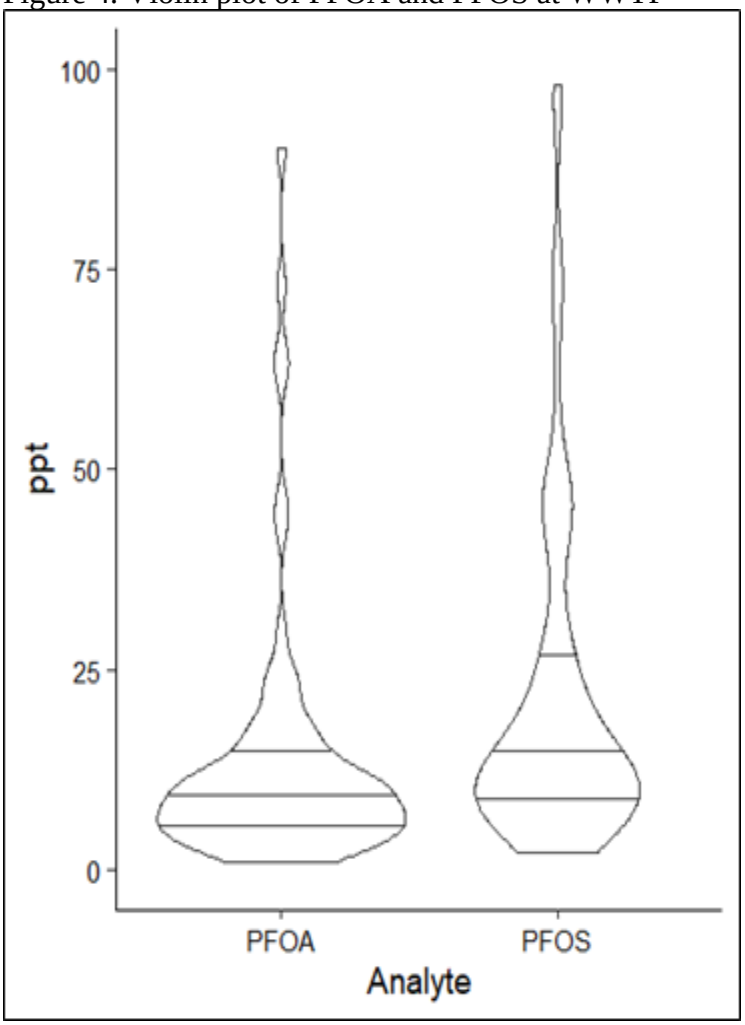
While it was determined by the NC state that GenX concentration should be lower than 140ppts as part of the health goal, the 70ppt concentration limit was set by EPA for combined PFOA and PFOS (Barnes, 2019a). Based on results from a previous raw water testing of North

Carolina's 320 municipal water treatment plants, there were no instances in which the detection of GenX, PFOA and PFOS was considered to surpass the health advisory level (Woolverton, 2020). However, recent 2019 samples from 28 wastewater treatment plants show Sanford, Raeford, and East Burlington had combined PFOA/PFOS levels over the EPA's 70 ppt health advisory limit, with PFOS more abundant [Figure 3]. A plot illustrating the spread of PFOA and PFOS samples by parts per trillion within the three-month sampling dataset indicates that the average levels for the sites with measurable levels are around 10ppt each [Figure 4]. It is worth noting that these high levels seem to be spikes [Figure 4] illustrating analytes over the three-month testing period, rather than consistently high which indicates a response to a notable event at the contaminant source.

Figure 3. Wastewater Treatment Plant sites with total PFOA and PFOS over 70ppt during 2019 sample

Site	PFOA	PFOS	Sum	Sample.Date
City.of.Raeford	NA	124.0	124.0	2019-09-16
City.of.Raeford	NA	73.6	73.6	2019-08-05
City.of.Raeford	NA	NA	0.0	2019-07-15
East.Burlington.WWTP	10.8	12.5	23.3	2019-09-17
East.Burlington.WWTP	64.6	56.4	121.0	2019-08-06
East.Burlington.WWTP	73.0	49.8	122.8	2019-07-16
Sanford-Big.Buffalo.Creek.WWTP	11.0	1000.0	1011.0	2019-09-04
Sanford-Big.Buffalo.Creek.WWTP	11.5	40.8	52.3	2019-08-06
Sanford-Big.Buffalo.Creek.WWTP	11.6	46.3	57.9	2019-07-08

Figure 4. Violin plot of PFOA and PFOS at WWTP



The diversity of the PFAS compounds and their widespread presence are significant barriers to conclusive testing and research endeavors [Figures 5-6; Figures 7-10]. Despite the replacement of legacy compounds with shorter chain PFAS compounds, PFOS and PFOA have a continual emergence in NC's waterways (Barnes, 2020b, 2020c). Findings from PFAS Testing Network revealed the detection of 48 PFAS compounds in 405 water sources (Ross, 2020). According to SELC, 14 PFAS compounds were detected in a drinking fountain at a Public Library in Chatham County, with a total concentration ranging from 157ppt to 489ppt during the two-month testing period, (Ross, 2020).

Figure 5. Analytes present within total PFAS by sample site, with indicator line at EPA's PFOA/PFOS health advisory level (2019 POTW dataset)

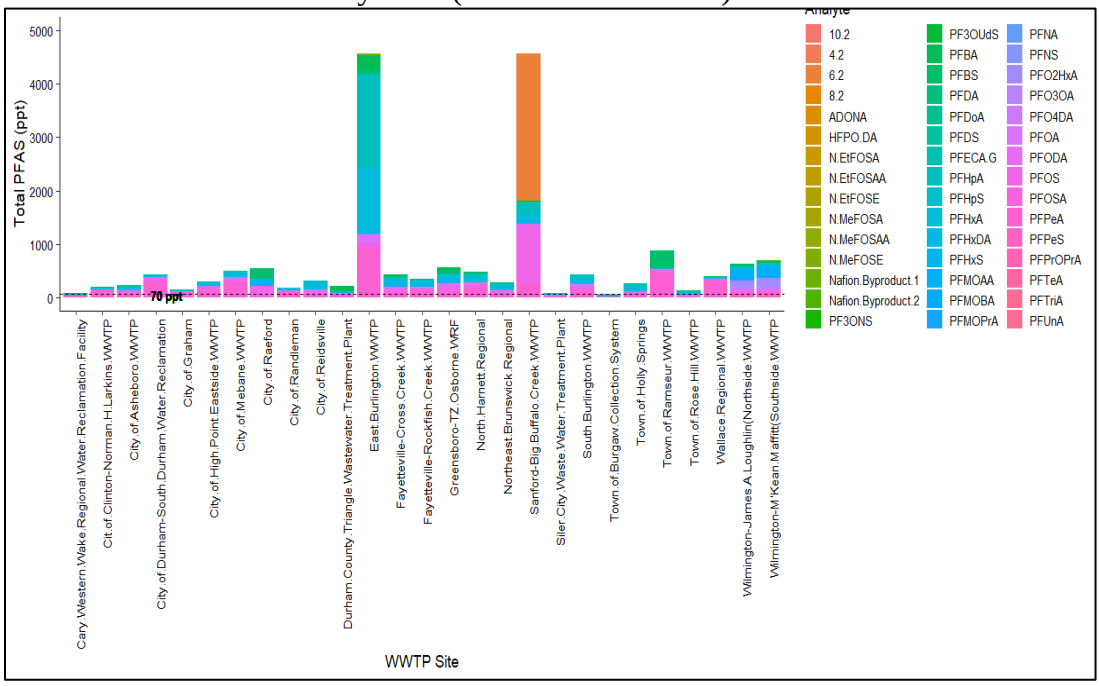


Figure 6. Analytes present within total PFAS by sample site, with indicator line at EPA's PFOA/PFOS health advisory level (2018 PWS dataset)

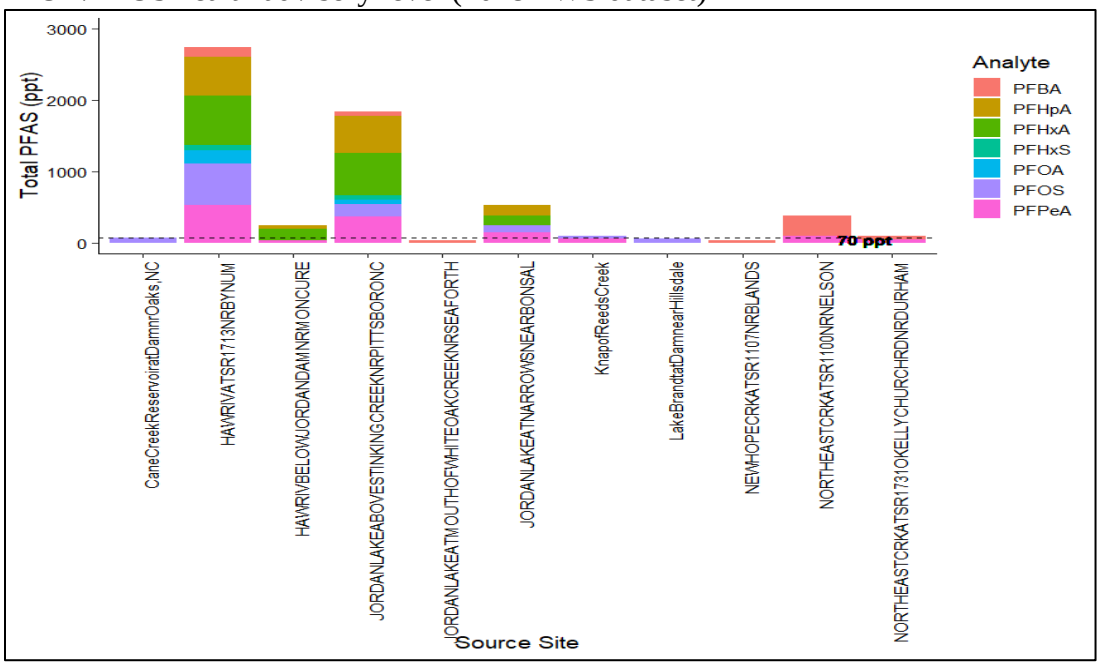


Figure 7. Top 10 most abundant analytes in WWTP samples

Analyte	Count
PFOA	74
PFHxA	73
PFOS	73
PFHpA	68
PFPeA	54
PFNA	45
PFDA	42
PFHxS	33
PFBS	26
PFBA	25

Figure 8. Number of Analyte Samples by Levels (ppt) at WWTP sites

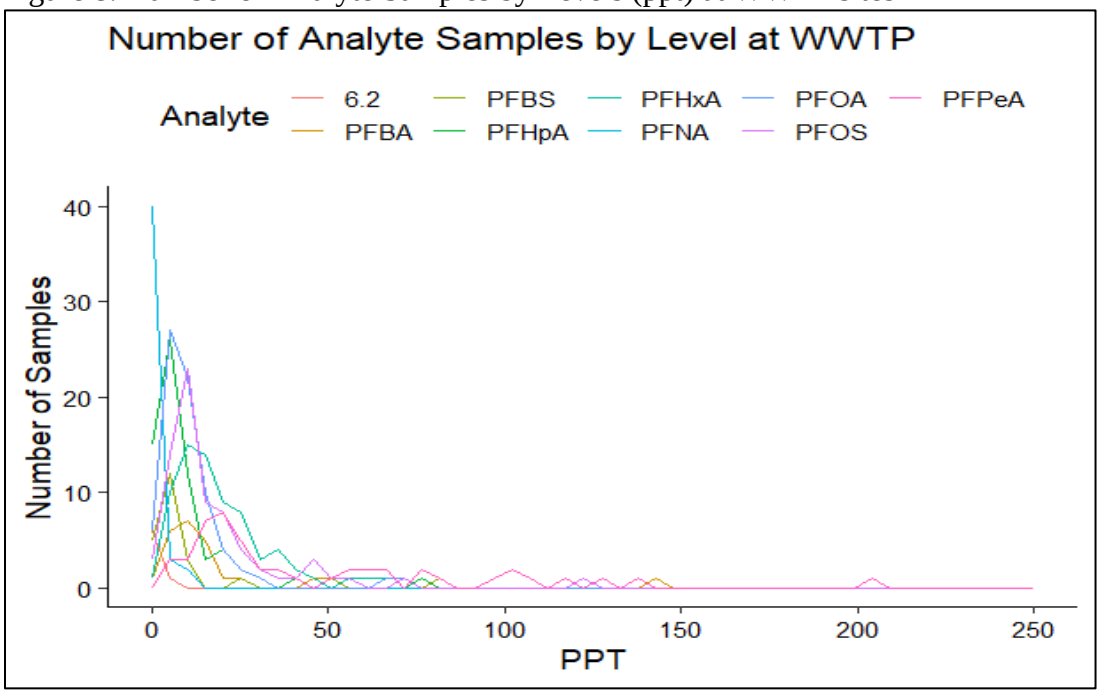


Figure 9. Number of Analyte Samples by Levels (ppt) at drinking water source sites

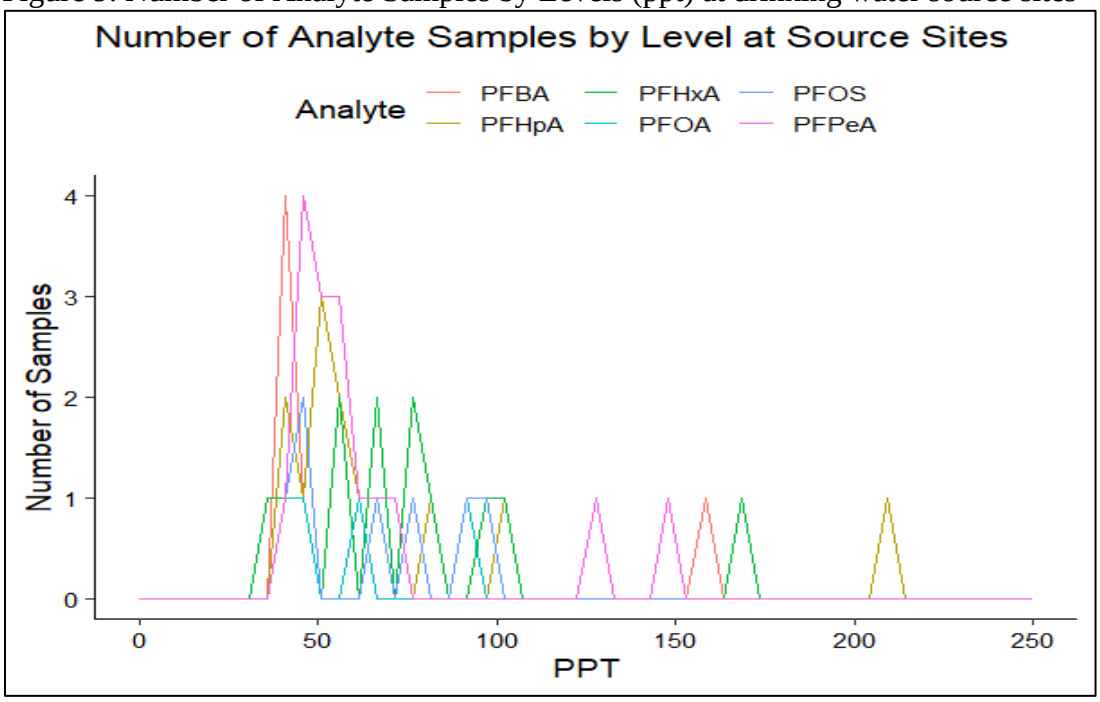
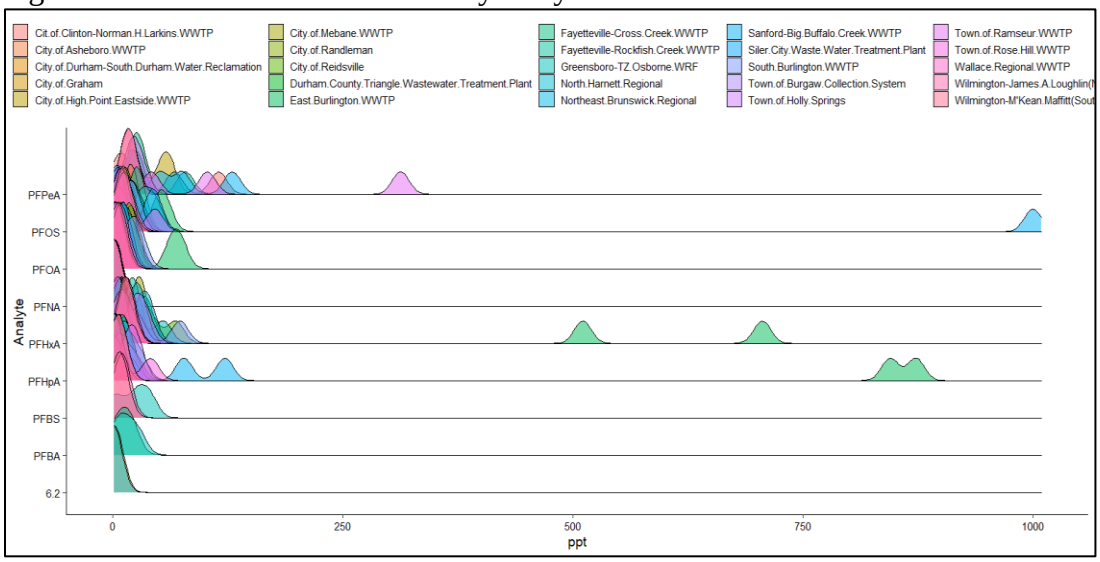


Figure 10. Abundance of Select Analytes by WWTP sites



The presence of multiple PFAS compounds in water samples makes regulation and treatment more difficult, as legislators must consider the impact of limiting only specific compounds and utility and wastewater treatment managers must choose remediation treatments that target the specific contaminants – or at least chain lengths – at their unique site. For example, treatments that are more effective at removing longer-chain PFAS (e.g., granular activated carbon)

will fail to adequately mitigate high total PFAS if the concentration is primarily of short-chained compounds [Figures 11-12].

Figure 11. Proportions of long and short chain lengths within total PFAS (2019 POTW dataset)

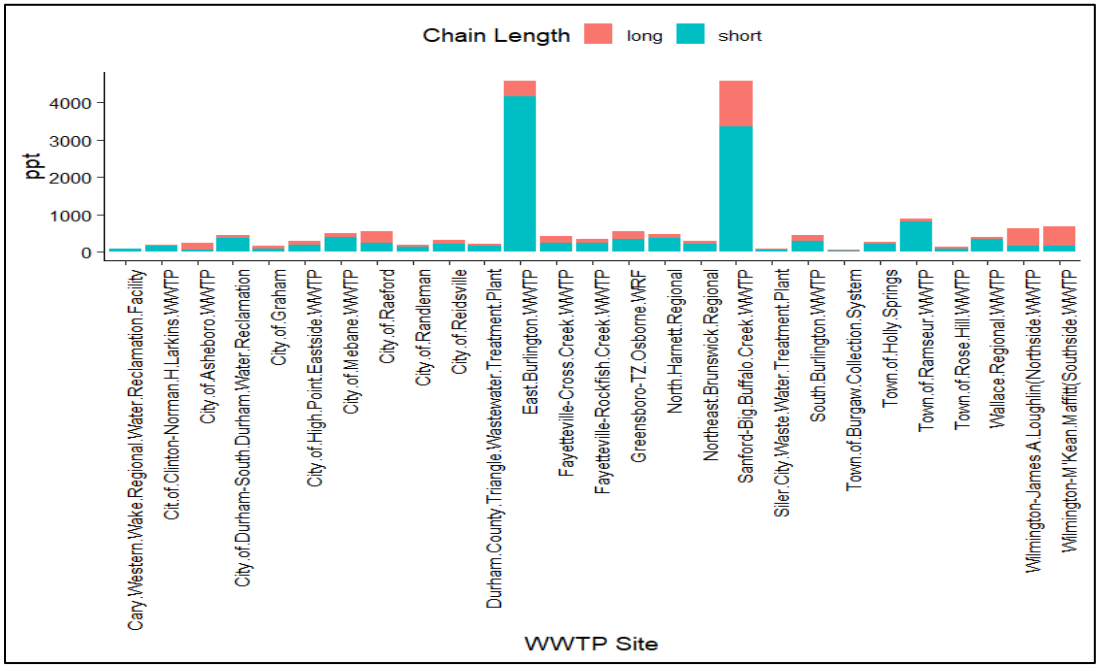
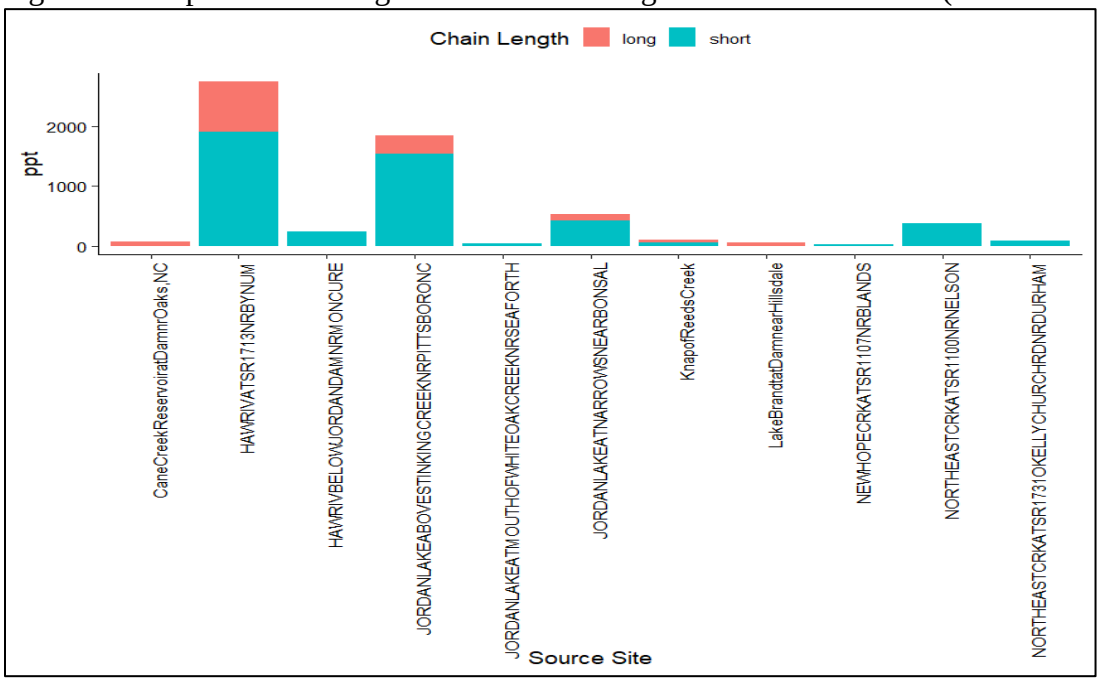


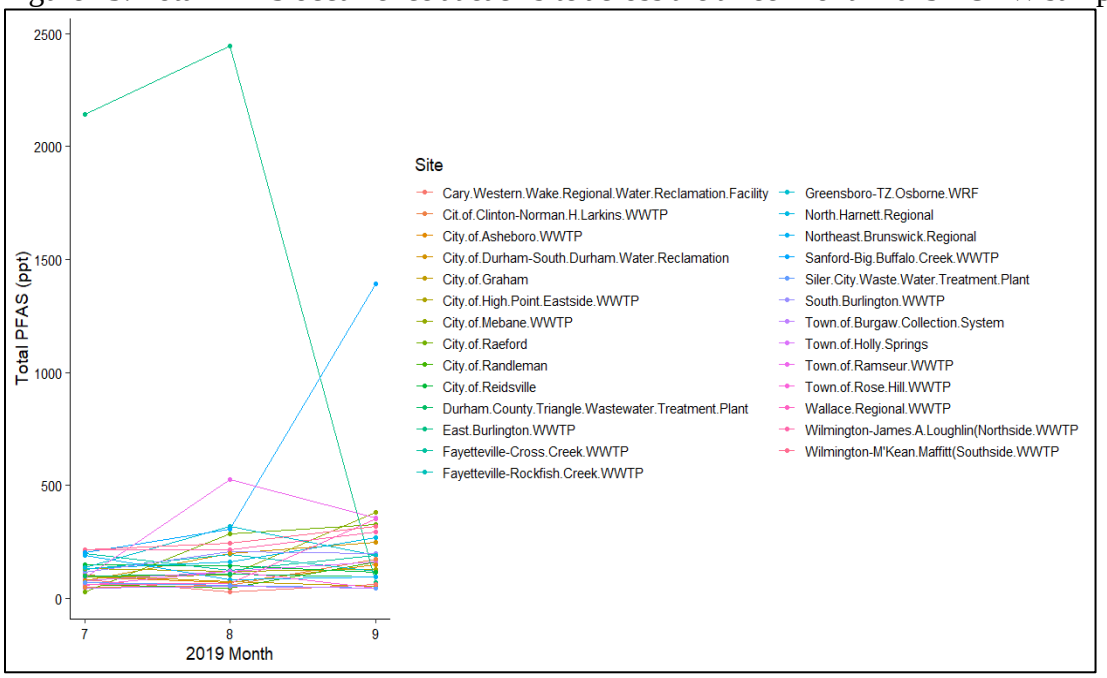
Figure 12. Proportions of long and short chain lengths within total PFAS (2018 PWS dataset)



Total PFAS

While later testing showed a reduction in both PFOA and PFOS concentration to closer to or below the EPA's health advisory, total PFAS levels remained high throughout the 2019 summer WWTP testing period [Figure 13].

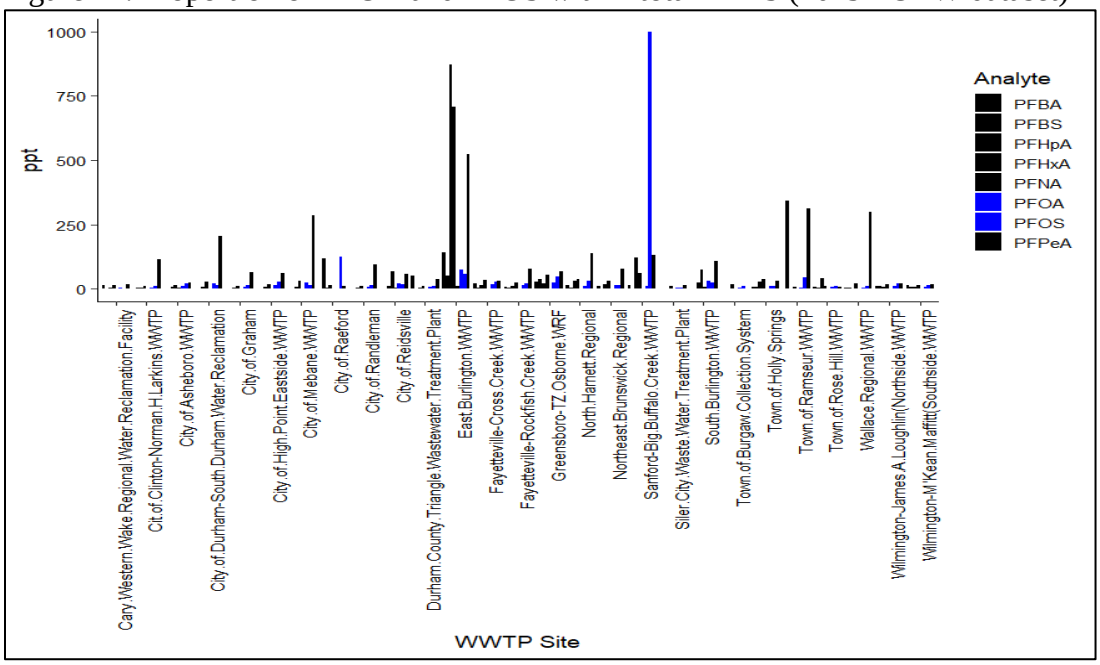
Figure 13. Total PFAS occurrence at each site across the three-month 2019 POTW sampling period



Of the WWTP, 27 sites had total PFAS over 30ppt and 13 over 70ppt. The By comparison, the 2018 drinking water source sites had 11 sites with total PFAS over 30ppt and 5 sites over 70ppt. Broadly, this means that despite low concentrations of specific individual compounds, there is the possibility of water samples still containing high concentrations of total PFAS. Traditional analyses only looking at PFOA and PFOS levels overlook potentially concerning high total PFAS levels, as evident in the September 2019 results from the Sanford WWTP where total PFAS was four times higher than PFOS alone (4026 and 1000 ppt respectively) [Figure 14]. The water within the Sanford treatment plant eventually discharges into Deep River (Barnes, 2020c). East

Burlington WWTP is another noteworthy site with total PFAS above 2000ppt in July and August, 2019.

Figure 14. Proportion of PFOA and PFOS within total PFAS (2019 POTW dataset)



For drinking water intakes, the PFAS Testing Network's samples demonstrated that Pittsboro had the highest level with 844.8 ppt (Woolverton, 2020). More cases were reported along the Yadkin-Pee Dee River and samples drawn from drinking water systems in cities like Durham, Cary, Chapel Hill and Apex in the Triangle also uncovered high levels of total PFAS (Barnes, 2020b, 2020c). It was also pointed out in other research findings that PFAS levels in both the lower Cape Fear region and Haw River were frequently much higher than the levels observed in drinking water samples taken by other research groups (Ross, 2020). It is almost intuitive to think that the raw water quality will have a direct and perpetual effect on the quality of finished water, especially when most treatment plants are unequipped with the technology to these contaminants.

Reporting Limits

To offer solid scientific evidence for PFAS occurrence, there must be quantitative data based on measurement and analysis that records and reports concentrations of PFAS compounds. Two common terms that are frequently used in reporting are method detection limit (MDL) and reporting limit (RL). While the MDL indicates the minimum greater-than-zero concentration that can be measured with 99% confidence, the reporting limit is the lowest reportable value with defined and reproducible level of certainty (Reade et al., 2019). Both numbers are laboratory-specific and vary among a series of PFAS compounds. For instance, according to EPA Method 537.1, the detection limits for 18 PFAS compounds are in the range of 0.53 to 2.8ppt (Reade et al., 2019). The more advanced instrument will result in greater capability of identifying and quantifying trace amount with minimum accuracy and precision issues. Both method detection limit and reporting limit are subject to constant updates due to the development of high-tech and high-sensitivity instruments and pressure from more stringent regulatory practices.

The reporting limits have an important role impacting research inferences and policy decisions. When individual analytes have high reporting limits (and therefore significant levels are unreported), it causes many water bodies with likely high total PFAS to be overlooked. Figures 15-16 show the range of reporting limits for each analyte from both the 2018 drinking water source and 2019 WWTP sampling. Note that some of these limits are above the EPA health advisory's 70ppt for PFOA and PFOS, and the additive nature of these compounds mean that even reporting limits of 10ppt could cumulate into hundreds of parts per trillion PFAS unreported. Given the frequently dramatic difference between the concentration of PFOA and PFOS compared to total PFAS present, it is crucial to have lower reporting limits beyond these two analytes in order to generate a more comprehensive picture of local contamination.

Figure 15. Max reporting limits of analytes present at WWTP

Analyte	Max Reporting Limit
N.EtFOSAA	1900
N.MeFOSAA	1900
PFDoA	420
PFBA	380
PFDA	380
PFTeA	380
PFTriA	380
PFUnA	380
HFPO.DA	354.62
4.2	333
PFHxDA	210
PFNA	210
PFODA	210
PFDS	200
PFHpS	170
PFNS	170
PFOA	170
PFOSA	170
PFBS	120
PFHpA	120
PFHxA	120
PFHxS	120
PFOS	120
PFPeA	120
PFPeS	120
6.2	89.6
8.2	85
PFPrOPrA	21
N.MeFOSA	18.9
N.EtFOSA	18.7
N.EtFOSE	9.43
N.MeFOSE	9.43

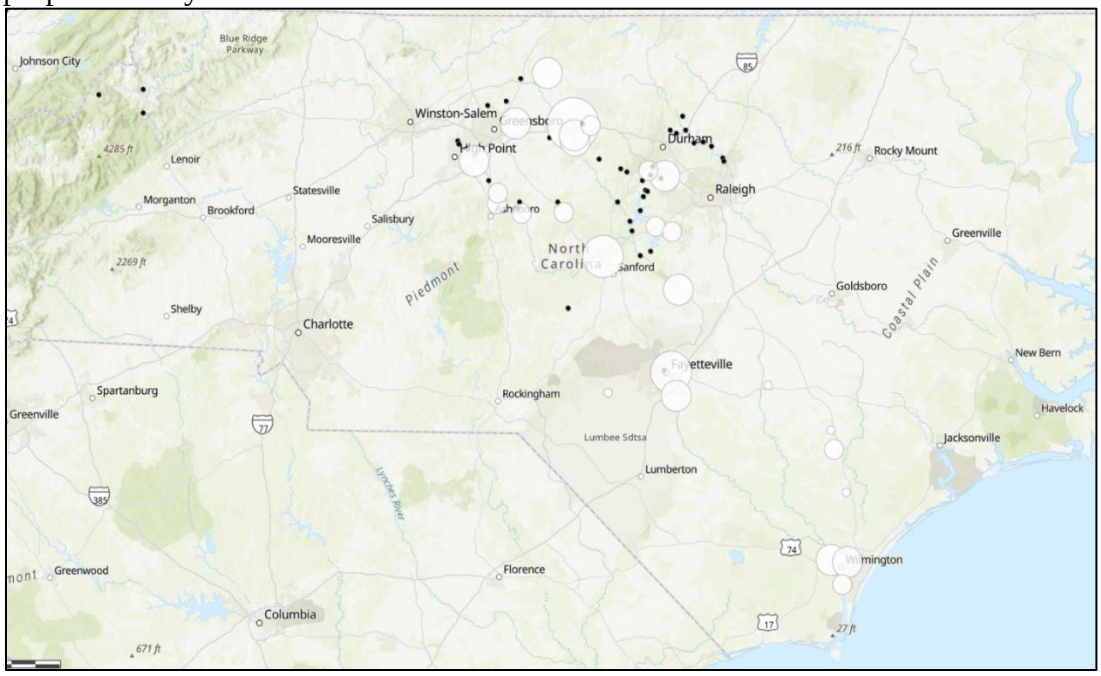
Figure 16. Max reporting limits of analytes present at drinking water sites

Analyte	Max Reporting Limit
6.2	310
PFUnA	310
NMeFOSAA	160
PFBA	160
PFDA	160
PFDoA	160
PFDS	160
PFNA	160
PFNS	160
PFTriA	160
8.2	83
4.2	82
PFHxA	82
PFOS	80
PFPeA	80
FOSA	42
HFPO.DA	42
PFBS	42
PFHpA	42
PFHpS	42
PFHxS	42
PFOA	42
PFPeS	42

Distribution in Water Resource of North Carolina

Given their ubiquitous presence, PFAS chemicals are found in every North Carolina water body sampled. The two current publicly available datasets for PFAS levels in North Carolina are DEQ's 2018 drinking water sources and 2019 wastewater treatment plant (WWTP) samples, which provided the foundation to the synthesis above. Drinking water source samples were collected at multiple points within each basin, while the circles proportional to total PFAS are WWTP sample sites which are considered a point source and only have one sample collected per plant [Figure 17].

Figure 17. Map of 2018 PWS and 2019 POTW sample sites, with POTW as circles proportionately sized to total PFAS found



Since these samples were collected in different years and within a short timeframe, the pattern and relationship of local PFAS distribution from pollution sources to drinking water sources is inconclusive. Furthermore, samples showing a wide fluctuation within a short timeframe indicates that the cause is not due to seasonal variation but perhaps to timing of testing after contaminant output at wastewater treatment sites or the types of PFAS since short chain

compounds degrade quicker. Clearly more investigatory sampling is needed to explain these patterns. The PFAS Testing Network's ongoing sampling creates a more consistent historical record of PFAS levels from river water and drinking water sources to uncover broad patterns to PFAS distribution and occurrence. At this time, the majority of those records are unpublished but interviews and conferences with the Network team convey the following current understanding of these patterns.

Hydrology

Hydrological factors such as precipitation frequency and intensity unsurprisingly impact when and how far away from a source levels are detected. Specifically, the distance and relationship between sewer plants and water intake treatment plants will impact what levels of – and when – PFAS is detected in raw water. Underscoring the importance of understanding timing and spatial relationships for sample testing, the Network sampled Sanford's raw drinking water a day after detecting a spike at the city's sewer plant (Barnes, 2020a). Unlike the 1,000 ppt of PFOS detected in September 2019, the latest sample did not find levels of PFOA or PFOS exceeding EPA health guidelines. Despite the city's water intake being downstream of its sewer plant (and therefore detectable PFAS levels would be present sooner than if upstream), Dr. Lee Ferguson – lead for the water sampling and analysis team – stated that it is "entirely feasible" contaminated water had not yet reached the treatment plant at the time of the sampling (Barnes, 2020a). Attempting to track the source, sampling upstream and downstream of the East Burlington Wastewater Treatment Plant provided "statistically higher levels downstream compared to upstream" (Ross, 2020).

Seasonality

Despite no detectible levels of PFOA or PFOS above 70 ppt from the Network's Pittsboro drinking water intake sample, the high levels of total PFAS from January to May, 2020 indicate that the deterioration and other forms of PFAS are substantially present, and that seasonality influences its occurrence. The Pittsboro samples identified a "twentyfold increase in levels from June to September" with the highest concentration at 760 ppt over the summer (Ross, 2020). The warmer temperature further made the upstream/downstream contrast more vivid: "five to ten times higher 100 yards downstream relative to upstream" (Ross, 2020). Dr. Stapleton concluded that the spatial and seasonal patterns suggest that the wastewater treatment plant is a major contributing source of PFAS, and also that industrial users are "discharging PFAS and PFAS precursors into those streams that are entering the [plant]" (Ross, 2020). The data supports the wastewater treatment plant as the primary source of PFAS in Pittsboro rather than rainfall or evaporation as distribution mechanisms (Ross, 2020). As testing continues, Jordan Lake (also along the Haw River) seems to present similarly. Dr. Stapleton stated that "the pattern of PFAS looks identical to what we're seeing in the Haw River" even if the lake's volume of water makes the concentration level lower (Ross, 2020).

Groundwater

In addition to the hydrological, seasonal, and directional factors, the range of PFAS contamination changes based on the water source. Dr. Stapleton indicated that while Pittsboro's tap water presented high levels of total PFAS, the area's wells had levels close to zero (Ross, 2020). Not only does this increase the likelihood that the river was the source, but it exposes a potential disparity in risk within the same geographic bound depending on whether a household's water source is groundwater or piped. Other well sampling further substantiates that only those

relying on wells near contamination sources are at risk. On the other hand, there is a very real concern that groundwater can carry contaminants and potentially further the distribution of the contaminants if connected to other sources. In addition to health concerns for those specific residents nearby, contamination can occur between water sources, such as the contamination from Chemours still occurring despite a prohibition on wastewater releases for the plant.

While water sampling and analysis so far has uncovered a better understanding of some sources and distribution of occurrence, it also exposes confusing results yet to be explained. In particular, how different levels of PFAS exist in reservoirs or treatment plants despite drawing from the same source. For example, the Pisgah National Forest (with no known local sources of PFAS) is the primary feed into the Mills River, sourcing the only PFAS compounds detected in Ashville's raw water (Walton, 2020). Similarly, testing at the Tuckaseigee Water & Sewer Authority found 1.2 ppt of GenX even though it has the same water source as Western Carolina University's water treatment plant, with no detectible PFAS compounds (Walton, 2020).

Who is Likely to be Affected

These findings indicate that the people most likely to be affected by waterborne PFAS are households using piped municipal water, particularly when the city's intake is downstream of wastewater treatment plants and/or other industrial dischargers. Without extensive testing at the tap to definitively quantify the amount of PFAS in the water, those who live in areas where contaminated river basins act as the supply source for their drinking water are at an unknown level of risk. Dr. Detlef Knappe – co-lead of the PFAST Network's testing team – estimates that of the Cape Fear River Basin's 1.5 million drinking water users, nearly 1 million "are affected by wastewater discharges containing high levels of industrial contaminants" (Scruggs, 2019). Blood samples detecting merging contaminants in Wilmington, NC's residents highlight this, although

given the many non-water sources of exposure, it is not currently possible to delineate a direct relationship to the source (Scruggs, 2019).

Data from groundwater wells indicate that the majority of well water have low or close to zero PFAS levels, unless they are close to a contamination source such as a military base, firefighter training facility, airport, or industrial production using PFAS or PFAS precursors.

Unnoticed Exposure

Overwhelming focus for PFAS testing, both nationally and within North Carolina, is for the combination of PFOS and PFOA. As discussed in other sections of this literature review, this attention is driven by technical capacity, EPA's health advisory level, and the history of industries producing these compounds prior to voluntary phase out. Despite being out of production, these two compounds are often the most detected in water samples (keeping in mind that many utilities across the country might not have the resources available to detect others), but the labs and expertise available in the Research Triangle allows for a more comprehensive look at the variations in PFAS compounds present. In particular, samples are detecting notable levels of those within the Perfluoralkylcarbonxylic acids (PFCA) analyte besides PFOA (specifically PFBA, PFPeA, pfhxA, PFHpA) which sometimes have higher levels than the sample's combined PFOA and PFOS concentration. This raises the concern that there could be a significant knowledge gap on the occurrence, distribution, and effects of non-PFOA or PFOS compounds.

The primary focus on identifying PFAS exposure is on residents using city water. This potentially overlooks the many rural and peri-urban households drawing from groundwater wells, but the well samples so far indicate that only those living near discharge sources would likely be at risk.

NHANES, the National Health and Nutrition Examination Survey, challenged the assumption that PFAS exposure is primarily through drinking water. Their survey found that 95% of Americans have detectable levels in their body despite many having drinking water without similarly detectable levels. (Reade et al., 2019). This speaks to both PFAS' bioaccumulating properties as well as the exposure threat from non-water sources, such as nonstick cookware and carpet material (Scruggs, 2019). Dr. Knappe echoes this: for example, Western North Carolina's water supplies have much lower PFAS levels that Central or and some Eastern regions, so residents in this region should "likely be more concerned about sources…within their own homes than about contamination of water supplies" (Walton, 2020).

Discussion and Recommendations

Recommendation Considerations

There are three significant considerations when determining mitigation response: cost, contaminant standard(s), and remediation technology. While RO and regulating as a class seem to be the best practice, these options are not always appropriate for affordability or cardiovascular health reasons. It is therefore crucial to understand the other options in order to make the best choice given unique local constraints.

Remediation

Reverse Osmosis: As discussed earlier, RO is the most effective available option for removing both short- and long-chain PFAS but it is more expensive than other treatment methods. For this reason, it should be prioritized at sites with notable short-chained analyte presence or high total PFAS. Without re-mineralizing water in post-treatment, it can also pose cardiovascular health risks. Therefore when designing this upgrade, it is crucial to consider the demographics of those using RO-treated water.

Granular Activated Carbon (GAC): Effective at removing long rather than short-chain PFAS, GAC's inconsistency and unpredictable effectiveness can be concerning. Since the majority of total PFAS found in North Carolina's wastewater treatment and public water supply (PWS) samples are short-chain analytes, there is a high probability that people will remain exposed to concerning levels if utilities choose this remediation option. However, it may still be appropriate for site-specific discharges (i.e., not PWS) with significant long-chain presence.

Regulation

Class MCL: Regulating PFAS as an entire class and establishing an MCL for total PFAS present addresses the "whack-a-mole" concern with chasing after every new industry compound. This approach is similar to regulating polychlorinated biphenyls (PCBs), which also are a class of persistent and bioaccumulating man-made chemicals with a range of toxicities (Reade et al., 2019). Furthermore, this approach works best for a system or agency who does not have access to the tools which allow for finer resolution in quantifying unique compound occurrence, especially since "there is no single methodology for isolating, identifying, and quantifying all PFAS" (Reade et al., 2019). On the other hand, many regulators and subject-matter experts advise against a group MCL because there is little information on all 5,000 PFAS toxicities and the various analytical methods detect different concentrations (Longsworth, 2020).

Analyte MCL; This regulation is "based on conclusions that human health effects, analytical limitations, and removal of drinking water contaminants vary by analyte." Toxicology studies demonstrate that individual PFAS can vary in potency and bioaccumulation (half-lives). Since there is more information available for terminal compounds (breakdown) than precursors in the same family, this approach would provide the state with greater flexibility to address an analyte without distinguishing within the group. The relevance of this approach depends on the state's

abundance for a given analyte and the availability of resources for testing and analysis (Longsworth, 2020).

PFOA + PFOS: As the two most studied long-chain compounds, there is more toxicity information and research available to make an informed regulatory decision (Longsworth, 2020). The EPA's health advisory shortens the jump to an MCL for the two, but since industries voluntarily phased them out, there are thousands more PFAS which similarly toxic effects and growing concentrations that would remain unregulated in this context.

Chain Length: Potentially taking a middle ground between the options, this regulation approach would create an MCL for long-chain compounds with similar structures (+/- two carbons) to PFOA and PFOS. As recognized in the analyte consideration, these compounds often occur together; have similar bioaccumulative patterns, lab detection limits, and fate and transport mechanisms; and human exposures often correlate which makes it hard to differentiate individual PFAS contributions to health effects (Longsworth, 2020).

Costs

Apart from point source-specific lawsuits or Consent Orders, the cost burden for an MCL (testing, treatment, and remediation) falls on public utilities unless otherwise structured. Therefore, it is crucial for either legislative funding to coincide with an MCL and/or for utilities to establish financing options or rate restructures that provide the necessary revenue to support this task. Looking at the costs within other states who already implemented an MCL (or other utilities who have upgraded their remediation treatment) can help estimate expectations locally. For example, the Northwest Water Treatment Plant's plan to double its production capacity from 24MGD and add RO is $179.4 million. In Minnesota, an industrial facility allocated $750,000 for retrofits and a GAC wastewater treatment in New Jersey ranges from $500,000 to $1,000,000 per MGD (10,000

people) (Longsworth, 2020). These numbers will further increase with expected growth and demand increases.

MEMORANDUM

Considerations for PFAS Mitigation

Overview of PFAS

This expanding group of over 5,000 analytes are present in water, non-stick surfaces, plastics, and firefighter foam. Everyone has exposure, but some people have concerningly higher levels depending on proximity to contamination sources, types of analytes present, and concentration ingested. Exposure is correlated to certain cancers, hypertension, developmental delays, and decreased vaccine response. The length of their strong carbon bonds impacts health risks and remediation options (e.g., granular activated carbon (GAC)[1] is ineffective at removing short-chain PFAS). Long-chain PFOA and PFOS are most commonly studied, leaving a limited understanding of impacts from total PFAS and other analytes.

Communities at Risk

To better understand household risk: (1) test extensively at-tap, (2) consider total PFAS beyond just PFOA and PFOS, (3) re-examine sampling sites with high analyte reporting levels, and (4) conduct further toxicology research on short-chain and other abundant analytes.

The lack of extensive at-home tap testing makes it impossible to conclusively determine individual household exposure via drinking water. There is also a high probability that there are overlooked water bodies with concerning levels of total PFAS due to high reporting limits[2]. Research indicates that households using groundwater wells only show high PFAS levels near contamination sources (industries, military bases, airports). In North Carolina, there were concerningly high PFAS levels present during the 2019 sampling at East Burlington, City of Raeford, and Sanford-Big Buffalo Creek, and the 2018 watersheds of Pittsboro, Haw River, Jordan Lake, North East Creek, and Cane Creek.

Children are particularly vulnerable because they drink more water per body weight and therefore consume a greater percentage of PFAS. Geriatric populations are at risk of additional cardiovascular repercussions if using reverse osmosis-treated water, and there is an equity concern for communities and households who cannot afford treatment upgrades to significantly reduce total PFAS.

Remediation Considerations

Granular Activated Carbon (GAC): Effective at removing long rather than short-chain PFAS, studies on at-home GAC show that it removed 73% of PFAS with inconsistent and unpredictable effectiveness. Since the majority of total PFAS found in North Carolina's WWTP and public water

[1] Chemical compounds measured in nanograms per liter (ng/L) or equivalent parts per trillion (ppt)

[2] Many analytes from 2018 and 2019 North Carolina water quality samples had reporting limits above 100ppt, with some reaching 1900ppt. Since they are not reported if detected below that limit, prior conclusions may miscommunicated reality and overlooked concerning sites.

supply samples are short-chain analytes, there is a high probability that people will remain exposed to concerning levels [Figures 11 and 13].

Reverse Osmosis: This treatment method is the effective option for removing both short- and long-chain PFAS. Since it is more expensive than GAC, it should be prioritized at sites with notable short-chained analyte presence or high total PFAS. RO removes minerals that are important to cardiovascular health, so there needs to be post-treatment remineralization to prevent additional health risks and it is crucial to consider the demographics of those using RO-treated water.

Policy Considerations

There is no current federal enforceable limit for total PFAS or individual analytes. The EPA set a non-enforceable health advisory limit for the sum of PFOA and PFOS at 70ppt and North Carolina's DHHS suggests 140ppt for GenX in drinking water. Over 13 states have pursued regulatory limits for PFOA, PFOS and some include other analytes. In these cases, short-chained PFAS often have a higher limit (e.g., Michigan's 8ppt for PFOA and 400,000ppt for PFHxA) due to specific toxicology calculations.

PFAS contamination is widespread and North Carolina has concerningly high levels in water basins sourcing over 2.7 million people with drinking water. A state-wide approach rather a local intervention is necessary. Section 303(d) of the Clean Water Act requires states to periodically assess and report water quality and identify "impaired waters" that need a strategy (such as Total Maximum Daily Load) to reduce input and restore functionality. If state or federal regulations pass, widespread monitoring would occur but only sources with notably high PFAS presence would need treatment upgrades.

If halting active PFAS discharge or modifying firefighter activity: Criteria for achieving reductions should have a benchmark based on total PFAS not just specific analytes and prioritize sites near well water-reliant communities or sources above drinking water intakes.

If expanding testing: Sample abundant long- **and** short-chained compounds. Given the small percentage PFOA and PFOS in total PFAS, testing that focuses narrowly on these two will overlook potentially dangerous PFAS levels. Conduct extensive at-tap testing to establish household risk assessments of drinking water exposure, since household exposure cannot be determined by water basin sampling. Build collaboration and transition plans between researchers and government agencies to make efficient use of resource capacities and avoid the incomplete conclusions that occur with siloed water quality testing. Centralize a historical database of agency and academic data on emerging compounds to comprehensively understand state-wide contamination and influences on its occurrence and distribution. Making this database publicly accessible (rather than a static report) supports accessibility and reduces costly analysis inefficiencies. Standardize sampling analyses and reports to avoid inconsistencies which make syntheses time-consumingly difficult and prohibitive (e.g., reporting limits, compounds sampled, and data format).

If regulating permissible levels: MCLs for specific analytes will overlook dangerous levels of existing and future chemicals, particularly short-chained PFAS. PFOA and PFOS are a small

percentage of total PFAS present in North Carolina. Pittsboro's 2018 drinking water source sample showed total PFAS (4000ppt) four times greater than PFOA (1000ppt) [Figures 5, 6 and 14]. MCL for total PFAS is considered best practice but may present undue financial burdens. Upgrading treatment to test for and dramatically reduce total PFAS is expensive and may be unnecessary depending on the chain length of predominant analytes present. However, there is a lack of sufficient understanding about the health risks associated with high levels of total PFAS exposure and upcoming studies may necessitate lower total PFAS regardless of chain length. MCLs based on chain length can target reductions based on the current understanding of health risks. Current toxicology calculations indicate that health risks are associated with different levels of exposure depending on analyte. Specifically, better-known long-chain analytes are associated with health risks at low levels. There is not enough information to fully understand the impact of short-chain exposure, but other states' health risk calculations give higher maximum limits to short-chained analytes. Comprehensive toxicology studies for the continuously expanding group of chemicals is infeasible, but regulation based on scientific inference of risks by chain-length is a strong approach to protecting public health without placing undue financial burden on treatment facilities.

Toxicology

Human Health Risks

Summary: PFAS compounds can imitate structures in the body that bind proteins and harm cell signaling pathways such as the thyroid hormone, leptin, and estrogen pathways. Exposure is associated with testicular and liver cancer, thyroid disease, high cholesterol, ulcerative colitis, hypertension during pregnancy, decreased vaccine response, decreased fertility and low baby birth weight.

Gaps: Since PFOS, PFOA, and GenX are the most commonly studied PFAS, there is a lack of information about risk associated with exposure to other analytes. Furthermore, the scientific community has insufficient knowledge about exposure routes, such as non-water contact (e.g., plastics and food) and the controlled lab and animal studies make it difficult to infer results and impact the accuracy of how these results represent human health effects.

Childhood Exposure

Summary: Since children drink more water per body weight, they consume proportionally more PFAS than adults. Exposure in children is associated with abnormal amounts of blood fats, developmental delays, later onset of menstruation, higher asthma occurrence, and limited immunity and kidney functions. Some studies indicate it may decrease immune response before and after vaccination and increase risk of celiac disease, Type I diabetes, and morbidity. The developmental delay is particularly concerning for children because their immune systems and bodies are still in development, therefore possibly causing a greater, long-lasting effect.

Gaps: Due to compounding and overlapping factors that impact health, the scientific community needs further research isolating PFAS-specific impacts on children. Furthermore, environmental factors are difficult to model in labs without more extensive data collection of PFAS levels varying in reality.

Ecological Impacts

Summary: PFAS uptake occurs in plants and animals (e.g., fish, insects, plants) when WWTP or industries output the contaminant into rivers and other bodies of water. It bioaccumulates in organism fat, so people will ingest PFAS when eating something that had high exposure (e.g., certain fish or livestock raised on lands using sludge land application) or frequently exposing themselves to low levels of PFAS that accumulate over time – with fattier organisms likely having higher levels. This also means that organisms with longer life cycles will likely have more PFAS because they had more years of cumulative exposure.

Gaps: There is limited knowledge on how different PFAS directly affect different organisms, which can be disastrous is it impacts keystone species (those which an ecosystem depends on, and if removed or destroyed could change the ecosystem drastically). The scientific community has not identified a baseline of PFAS found in nearly every organism, and therefore unsure how to determine which species have significantly high levels or conclusively determine concerning ingestion sources.

Occurrence and Distribution

PFAS Cycle

Summary: PFAS enters the environment from water and airborne discharge. Infiltration processes can transport PFAS from land through soil and into the groundwater system (e.g., leachate water carries contaminates after percolating through landfills), and tts strong carbon chains cause bioaccumulation in plants and animals thereby becoming part of the food chain.

Gaps: There is limited knowledge on the extent and environmental factors impacting identified exposure pathways as well as its interaction with non-PFAS chemicals, which impacts conclusions and analyses of its presence and precursors (compounds before they become PFAS).

Associated Sources

Summary: Most PFAS come from industrial releases (e.g., metal, textiles, rubber, adhesives, pesticides), wastewater treatment plant discharge; runoff carrying fire-retardant foam from military sites and airports; water infiltrating through landfills; and biosolids applied as fertilizer. The Lear Corporation and Arclin USA factories in North Carolina had high levels in their effluent, and historically the DuPont facility manufactured PFOA and GenX despite knowing its severe negative health impacts.

Gaps: The lack of PFAS regulation causes a severe overlook of many factories that may still produce and discharge toxic levels of PFAS because there are no testing requirements. While the primary public focus is on Chemours/DuPont, there are many other potential dischargers that need further consideration.

Occurrence in North Carolina

Summary: North Carolina is the third highest state for PFAS in water. Discontinuing PFOA and PFOS production has not prevented their persistent presence, but these are often not the dominant

analytes in total PFAS (e.g., Pittsboro's 2018 Public Water System sample showed total PFAS four times greater than PFOA, at 4000ppt and 1000ppt respectively). Total PFAS levels remain consistently high, particularly at Sanford-Big Buffalo Creek, City of Raeford, and East Burlington WWTP (each with a PFOA/PFOS sum above the 70ppt EPA Health Advisory Level); Cape Fear, Haw River, Cane Creek and Yadkin-Pee Dee River Public Water Sources; and Durham, Cary, Chapel Hill and Apex water systems.

Gaps: Research is inconclusive about the wide short-term variability and why high stream flow rates do not necessarily lower PFAS concentration, but one hypothesis is that storm events carry more of the pollutant. Labs with different testing tool abilities dramatically impact conclusions, and high reporting limits pose concerning gaps in identifying risks and unnoticed sources.

Distribution in North Carolina

Summary: Public comments from the PFAS Testing Network indicate that precipitation and temperature impact distribution and underscore the importance of testing upstream and to identify spatial patterns and validate PFAS sources. Levels can differ between bodies of water despite sharing the same source input. Similarly, low levels in one drinking source (well water) does not guarantee safe levels in another (public tap connections) because they differ in proximity and connection to contamination sources.

Gaps: Correlations between specific analytes and their contributing sources (beyond PFOA and PFOS commonly found in firefighter foam) and their rates of travel and decomposition in water – necessary for estimating and mitigating downstream contamination – are undetermined. Additionally, rural and peri-urban communities often receive less notification and testing, therefore have insufficiently known risks.

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